

DRAFT

Aquaculture and Fisheries Development in  
in Puerto Rico and the U.S. Virgin Islands

by

Melvin H. Goodwin and Paul D. Sandifer

This is a draft of an Office of Technology Assessment document. It is being made available solely for review purposes and should not be quoted, circulated, reproduced or represented as an official OTA document. The material is undergoing revision and should not be considered as final.

October 1985

DRAFT

OCT 15 1985

Aquaculture and Fisheries Development  
in Puerto Rico and the U.S. Virgin Islands

by

Melvin H. Goodwin

Paul D. Sandifer

Draft Report to

United States Congress  
Office of Technology Assessment

## Contents

|                                                                                           |    |
|-------------------------------------------------------------------------------------------|----|
| Abstract . . . . .                                                                        | i  |
| I. Introduction . . . . .                                                                 | 1  |
| A. Significance to Economic Development . . . . .                                         | 1  |
| B. Relevant Ecosystems, Species, and Capacities for<br>Harvest and Culture . . . . .      | 2  |
| II. Fisheries Development and Management . . . . .                                        | 11 |
| A. Overview of Capture Fisheries . . . . .                                                | 11 |
| B. Overview of Resource Management Technologies . . . .                                   | 14 |
| C. Principal Factors Affecting Harvest and Management                                     | 16 |
| D. Forecast of Effects of Continued Exploitation<br>Trends . . . . .                      | 18 |
| E. Impact of Potential Exploitation Technologies . . . .                                  | 20 |
| F. Requirements and Impacts of Resource Management<br>Technologies . . . . .              | 22 |
| III. Aquaculture . . . . .                                                                | 28 |
| A. Potential for Aquaculture Development . . . . .                                        | 28 |
| B. Applicability of Various Types of Aquaculture to the<br>U.S. Caribbean . . . . .       | 31 |
| C. History of Aquaculture in Puerto Rico and the<br>U.S. Virgin Islands . . . . .         | 36 |
| D. Social and Ecological Impacts of Previous<br>Aquaculture Development . . . . .         | 37 |
| E. Criteria for Successful Aquaculture Projects . . . .                                   | 39 |
| F. Requirements and Expected Impacts of Appropriate<br>Aquaculture Technologies . . . . . | 39 |
| IV. Relationships Between Capture Fisheries and Aquaculture                               | 41 |

Contents (continued)

|                                                                                                        |    |
|--------------------------------------------------------------------------------------------------------|----|
| V. Summary . . . . .                                                                                   | 43 |
| A. Problems and Opportunities . . . . .                                                                | 43 |
| B. Relevant Agencies, Policies, Programs and<br>Regulations . . . . .                                  | 44 |
| C. Objectives . . . . .                                                                                | 48 |
| D. Recommended Action . . . . .                                                                        | 48 |
| E. Assessment of Consequences . . . . .                                                                | 50 |
| Bibliography . . . . .                                                                                 | 53 |
| Appendix 1 -- Criteria for Successful Aquaculture Projects                                             | 60 |
| Appendix 2 -- Requirements, Problems, and Impacts of<br>Appropriate Aquaculture Technologies . . . . . | 63 |

Abstract

The nearshore fishing industry of Puerto Rico and the U.S. Virgin Islands is a multi-million dollar industry, producing  
|| excess of seven million pounds of seafood in 1982. In addition, 1  
nearshore resources have high aesthetic value and are an  
important component of the tourist industry. Major habitats  
include coral reefs, mangroves, and sea grass beds, many of which  
are threatened by development and exploitation patterns not  
consistent with sustained use. Harvest of traditional fishery  
|| resources typically approaches or exceeds maximum sustainable  
yield. Current use of nearshore resources is constrained by  
relatively small size of productive areas, multispecies nature of  
exploited stocks, ciguatera, and susceptibility to storm damage.  
Management systems are in place which, with modification, can  
significantly improve use of these resources.

Despite limitations, there are potentials for development of  
|| capture and culture fisheries which can significantly benefit the 2  
U.S. Caribbean territories. Recommendations for achieving these  
benefits include development of management plans for major  
nearshore ecosystems, limitation of harvest effort, support to  
local resource management initiatives, ciguatera research, and  
collaboration with other countries of the Lesser Antilles.  
Specific recommendations are provided for government agencies and  
private institutions.

## I. Introduction

### A. Significance to Economic Development

The nearshore fishing industry of Puerto Rico and the U.S. Virgin Islands produced more than seven million pounds of seafood in 1982, and employed an estimated 2,450 fishermen. Excluding tuna caught in distant waters, about 90% of commercial landings in Puerto Rico are from nearshore stocks (Juhl and Dammann, 1976). Of these, about 60% are shallow-water reef fish whose landed value in 1982 totalled \$8.7 million for Puerto Rico and the U.S. Virgin Islands combined. Though clearly significant as a million-dollar industry, this level of production falls far short of meeting the local demand for fresh seafood which has increased markedly with expanding tourism. Nearly 60 million pounds of seafood valued at \$48 million are imported annually to Puerto Rico and the U.S. Virgin Islands. 3

In addition to providing an important source of food, nearshore marine resources are a vital part of the tourist industry: Coastal environments (beaches, sheltered lagoons, coral reefs) are among the islands' primary attractions. At least 1.8 million pounds of fish are landed annually by sport fisheries in Puerto Rico and the U.S. Virgin Islands (Clapp and Mayne, 1979; Caribbean Fishery Management Council, 1984). 4

B. Relevant Ecosystems, Species, and Capacities for Harvest and Culture

1. Ecosystems

Three major ecosystems are significant to nearshore marine resources of Puerto Rico and the U.S. Virgin Islands. 5

a. Coral reefs -- Tropical oceans have been popularly characterized as "biological deserts", because nutrient levels are much lower than in temperate regions and primary biological production is correspondingly reduced. Continuing the analogy, coral reef areas) have been described as "oases of productivity" due to the level of biological activity made possible by organisms which increase available nutrients (e.g., algae which "fix" atmospheric nitrogen into forms useful to other species) and recycling of nutrients within these ecosystems. Coral reef systems are responsible for much of the nearshore fisheries potential of Puerto Rico and the U.S. Virgin Islands. The reef structure provides shelter for many species and surface areas upon which a variety of organisms grow and in turn become food for other reef dwellers. Coral reefs also serve as nursery areas for fish species which move into other habitats as adults. In addition to direct benefits to fisheries, some coral reefs provide natural breakwaters which protect shorelines from sea erosion. The variety in form and color characteristic of reef 6

species is a well-known recreational attraction for residents and tourists alike.

b. Mangroves -- Like coral reefs, the spatial complexity of mangroves provides shelter, nursery areas, and growing surfaces for a variety of important species. The intricate root systems of mangroves act as a trap for sediment and land-derived detritus. Decomposition of this material releases nutrients, and mangrove "swamps" may have greater biological productivity than surrounding waters. These functions are not widely acknowledged, however, and mangroves are frequently destroyed in the process of "developing" waterfront areas. The Puerto Rico Coastal Management Program (1978) states that three-quarters of the island's original mangroves have been destroyed.

c. Sea grass beds -- Some of the most valuable marine fishery species (e.g., queen conch and spiny lobster) are associated with sea grass beds for at least part of their life cycle. The leaves and interwoven roots provide extensive shelter for small organisms and grazing surfaces for a variety of species. Sea grass beds provide additional feeding areas for species on nearby reefs, and the variety of fishes tends to be higher on reefs close to these habitats.

It is important to recognize that these systems are often adjacent and mutually interactive. Mangroves, for example, trap sediment from terrestrial runoff which can be highly detrimental

to coral reefs and sea grass beds. Similarly, coral reefs in some areas function as breakwaters which protect seagrass beds and mangroves from the full impact of sea waves. Nearshore fisheries may also depend upon a combination of these ecosystems. Larvae of spiny lobster, for example, commonly settle among the prop roots of mangroves, move onto adjacent sea grass beds or shallow reefs as juveniles, then into deeper reef habitats as they mature.

## 2. Species

Six major species and groups of species are involved in the current harvest:

a. Shallow reef fisheries -- Most shallow-water bottom-dwelling fish in Puerto Rico and the U.S. Virgin Islands are associated with coral habitats. More than 300 fish species are found in these areas, of which about 180 are harvested for human consumption.

b. Deep reef fisheries -- Between 145 and 270 m snapper and grouper species are often found in areas where the slope is rocky or steeper than 30 degrees (Peacock, 1976). Groupers often occupy crevasses or holes, while snappers frequently congregate around outcrops. Both types of area can be difficult to fish, and deepwater demersal fisheries are generally thought to be underexploited in most of the Lesser Antilles.

c. Pelagic fisheries -- Population dynamics of pelagic fishes are not well understood, and the migratory tuna stocks which have received greatest attention (through the International Commission for the Conservation of Atlantic Tuna) are not considered nearshore species. Recent work by Oxenford and Hunte (1984) indicates that Barbados, St. Vincent, St. Lucia, and possibly Grenada are exploiting the same stock of dolphin (Coryphaena hippuris) whose northern limit is the U.S. Virgin Islands. The same circumstance may be true of other pelagic species, and suggests that collaboration may be necessary with other countries in the Lesser Antilles to achieve effective management and optimum use of these resources. Shark resources are generally underutilized in the Lesser Antilles, but are particularly vulnerable to overexploitation because of low reproductive potential, slow growth rates, and greater age-at-maturity than other fishery stocks.

13

imp. of cooperation

✓

||

d. Spiny lobster -- Panulirus argus is the most highly valued fishery species in the Eastern Caribbean. This species has a long (6 months or more) larval life which makes it difficult to determine the origin of adult populations. Consequently, stocks in Puerto Rico and the U.S. Virgin Islands may depend upon production in other locales. As is the case with dolphin fisheries, this potential interdependence offers substantial

||

14

||

justification for collaboration with other Lesser Antillean countries in developing marine resource management strategies.

e. Conch -- Queen conch (Strombus gigas) is the most important edible mollusc in the Eastern Caribbean. Because they are seldom found in depths exceeding 30 m, these stocks are highly vulnerable to overfishing. There have been several efforts to develop techniques for conch culture. Because post-larval conch require roughly three years to reach maturity, the grow-out phase is a serious problem for would-be culturists. A 1982 review of progress in conch mariculture (Berg, 1983) concluded that "commercialization of conch aquaculture does not seem economically feasible at this time." The prospect of "re-seeding" depleted areas with hatchery-produced conch requires pilot scale evaluation. 15

f. Other species -- In addition to the above groups, octopi (Octopus vulgaris), mangrove oysters (Crassostrea rhizophorae), top shells (Cittarium pica), and several other invertebrates are also harvested, but these species amount to less than 2% of total landings. 16

### 3. Capacities for harvest and culture

Harvest of nearshore marine resources takes place primarily in the vicinity of coral reefs and seagrass beds, though a few species are selectively taken from mangrove and rocky shore habitats. Because juvenile fishes are often found in these 17

habitats and because adults of some species aggregate during spawning seasons, it is relatively easy to deplete many stocks. Fishing in breeding aggregations of Nassau grouper has resulted in the virtual annihilation of these populations in the U.S. Virgin Islands (Caribbean Fishery Management Council, 1984). Munro (1974) reported that in heavily exploited Jamaican fisheries, "negligible numbers of fishes survive long enough to spawn." Recent fishing effort targeted toward deep reef resources in Puerto Rico and the U.S. Virgin Islands may have significantly depleted these stocks, even though a relatively small number of vessels and fishermen were involved (A. E. Dammann, personal communication, 17 June, 1985). Maintenance of populations under these conditions depends upon production elsewhere, and increased fishing effort in the latter areas is likely to lead to collapse of the fishery.

The fin fish harvest typically includes a variety of species, while the harvest of invertebrates is usually targeted toward single species. In both cases, estimation of sustainable yields is problematic. Table 1 summarizes maximum sustainable yield (MSY) estimates for some stocks, but it is stressed that these estimates are liable to considerable error for reasons discussed below (section II.B). An MSY estimate in excess of current landings does not necessarily indicate underutilization because all landings are not reported, and because catches

Table 1

Estimates of Sustainable Yield for Some Fishery Stocks of  
Puerto Rico and the U.S. Virgin Islands

| Species or<br>Species Group | Location                | Shelf<br>Area<br>(sq km) | MSY<br>(mt/yr) | Landings [Year]<br>(mt) |
|-----------------------------|-------------------------|--------------------------|----------------|-------------------------|
| Shallow-water<br>reeffish   | Puerto Rico             | 5538                     | 2431 (1)       | 1489 [1982] (1)         |
|                             | U.S.V.I.                | 1967                     | 1038 (1)       | 1903 [1982] (1)         |
| Spiny Lobster               | Puerto Rico             | 5538                     | 1418 (2)       | 15.4 [1978] (1)         |
|                             | St. Thomas-<br>St. John | 1629                     | 552 (2) )      | )                       |
|                             | St. Croix               | 343                      | 193 (2) )      | ) 49.5 [1980] (1)       |
| Conch                       | Puerto Rico             | 5538                     | 562 (3)        | 1682 [1981] (4)         |
|                             | St. Thomas-<br>St. John | 1629                     | 165 (3)        | not available           |
|                             | St. Croix               | 343                      | 27 (3)         | 26.8 [1979] (3)         |

Sources:

- (1) CFMC, 1984
- (2) CFMC, 1980
- (3) Wood and Olsen, 1983
- (4) Ballantine and Appeldoorn, 1983

decline when MSY is exceeded. The latter circumstance indicates the need for information on catch per unit effort as well as MSY. Despite the uncertainty of yield estimates, available information and past experience suggest that development of these resources should proceed with caution.

As in other Caribbean islands, harvest and culture in the nearshore marine environments of Puerto Rico and the U.S. Virgin Islands are constrained by several features:

a. The physical size of productive areas is smaller than in other parts of the world where commercial fisheries have been developed. The continental shelf area of Puerto Rico and the U.S. Virgin Islands is less than 3000 sq mi (Caribbean Fishery Management Council, 1984), compared to the 76,000 sq mi shelf area of the Bahamas or the 175,000 sq mi shelf area of the Gulf of Mexico (Klima, 1976). In addition, highly productive habitats are not uniformly distributed over the entire shelf; their actual occurrence is typically less than half the total shelf area (e.g., Munro, 1977). Some stocks are confined to even smaller fractions of the shelf (e.g., deepwater snappers are most abundant on the shelf perimeter). The limited extent of highly productive areas is a particular constraint to culture of filter-feeding organisms (such as oysters or mussels) in natural waters (i.e., without fertilization).

19

20

11

b. The multispecies nature of most fishery stocks means that catches often contain a mixture of high-value and less desirable species. In fact, experience with the development of deep-water fisheries has shown that the proportion of less desirable species tends to rise with increasing exploitation (e.g., Vidaeus, 1970). Because the contribution of individual species to total production is relatively small, fishing operations targeted toward particular species may easily overexploit the resource.

21

c. The rugged topography of coral reefs makes it impossible to use towed gear (e.g., trawls) employed in many commercial fisheries. Aside from this difficulty, such gear is undesirable in reef and seagrass areas because of the inevitable damage to the productive habitats. Moreover, while such highly efficient non-selective gear is suitable in temperate waters, the limited resource base of tropical island fisheries cannot support this level of fishing effort.

22

d. Ciguatera (tropical fish poisoning not related to spoilage) poses a major obstacle to marketing fish in Puerto Rico and the U.S. Virgin Islands. Olsen and Wood (1982) state that 50% of the fish species landed (comprising 56% of the landings by weight) have been implicated in ciguatera poisoning. Large fishes (particularly snapper, grouper, kingfish and jacks) caught in depths less than 60 m are more likely to be toxic than other fishes. These species frequently constitute a significant portion

23

of the fisheries potential in coastal areas, but cannot be sold due to the risk of poisoning.

e. Nearshore marine environments in the Caribbean are susceptible to damage by tropical storms; the Lesser Antilles have been subjected to four hurricanes in the past six years. These storms can alter coral reefs, seagrass beds, and shorelines overnight (e.g., Rogers et al., 1982; Woodley et al., 1981). Rogers (1985) points out that adverse impacts on fisheries due to habitat destruction are increasing, and that because reefs, mangroves and seagrass beds are interrelated, destruction of any of these habitats will adversely affect local fisheries. Potential storm damage to seawater ponds or cages is a constant risk faced by mariculture operations using these systems.

## II. Fisheries Development and Management

### A. Overview of Capture Fisheries

There is ample evidence that fishing played a significant part in the lives of Amerindians who inhabited the Caribbean islands prior to European settlers, though it is not possible to assess the relative importance of fishing compared to other activities. During the colonial period, fishing was never a major occupation (Suarez-Cabro, 1974). Commercial fishery development in Puerto Rico began in 1941 under the Department of Agriculture, when the influx of military personnel substantially increased

local demand for fish. This demand has been perpetuated by tourist hotels built to stimulate the economy. After the war, the program was transferred to the Puerto Rican Agricultural Development Corporation which emphasized offshore fisheries, and acquired a converted tuna clipper for experimental operations. The program terminated in 1947. Subsequent activities undertaken by the Division of Fish and Wildlife include establishment of fishing gear distribution centers, a fishery credit scheme, construction of facilities for gear storage and landing of fishing boats, and fishermen training.

Between 1974 and 1976 about 30 modern fiberglass fishing vessels (25 - 51 ft overall length) were introduced to the Puerto Rico fishing fleet. Twelve were acquired under programs of the Department of Agriculture, and the remainder by fishermen's associations through the Community Action Program of the Department of Labor (Juhl and Dammann, 1976). The objective of these acquisitions was to increase local fish production and to modernize traditional fisheries. Between 1976 and 1982, the number of fishermen in Puerto Rico increased from 1230 to 1872, while the number of fishing vessels rose from 865 to 1449 (Juhl and Dammann, 1976; Caribbean Fishery Management Council, 1984). This development pattern has had a striking impact on Puerto Rico's nearshore resources. Because of rising fuel costs, larger "offshore" boats have tended to fish closer to shore. In 1974

26

the waters of Puerto Rico were characterized as "very nearly overfished" and "heavily exploited" (Brody and Slocum quoted by Juhl and Dammann, 1976; Kawaguchi, 1974). In 1976, Juhl and Dammann reported a harvest of about 1.1 million kg from shallow reef areas in Puerto Rico; in 1982 landings from the same fisheries totalled about 1.3 kg. But the number of traps set increased from less than 9000 in 1976 to more than 23,000 in 1982; catch per trap set declined progressively during this period by more than 50%; a classic indication of overfishing.

Fisheries development efforts have been much less intensive in the U.S. Virgin Islands. But even modest increases in fishing effort coupled with technological innovations may have exceeded natural productive capacity. In 1970, the fishery stocks of the U.S. Virgin Islands were "not being endangered by overfishing" (Swingle, Dammann, and Yntema, 1970). Between 1970 and 1982 the number of fishermen in the U.S. Virgin Islands increased from 400 to 578, while the number of traps set increased from 1041 in 1975 to 2588 in 1982. Between 1975 and 1979, catch per trap set increased by 78%, but declined by 27% between 1979 and 1982.

Declining catch per unit effort has been accompanied by a rise in value of the catch. Between 1975 and 1982, the value of shallow-water reef fish landings in Puerto Rico increased from \$1.149 million to 2.194 million; while the value of similar landings in the U.S. Virgin Islands increased from \$1.223 million

27

11

28

to \$6.483 million. The difference is due to (a) an increase of 168% in actual landings in the U.S. Virgin Islands compared to less than 1% in Puerto Rico, and (b) a higher price per lb in the U.S. Virgin Islands (in 1982, \$1.78 in the U.S. Virgin Islands compared to \$0.77 in Puerto Rico).

#### B. Overview of Resource Management Technologies

As the above discussion would suggest, application of technology to manage nearshore marine resources of Puerto Rico and the U.S. Virgin Islands has not kept pace with development of technology for exploitation. Historically, these resources have not been regarded as highly important. Marine harvest activities have not played a central role in local societies, and informal or traditional regulatory systems have not developed (in contrast to island communities in the Pacific where marine resource use has been an integral societal element for generations).

Formal regulatory systems for marine resource management are relatively recent. The Fishery Conservation and Management Act of 1976 (PL 94-265) established a fishery conservation zone of 200 nautical miles within which the United States has exclusive management authority for fishery resources (except for highly migratory pelagic species). The Act also established eight Regional Fishery Management Councils which have the responsibility for developing management plans for exploited species or group of species) within their respective regions. The

Caribbean Fishery Management Council has jurisdiction over Puerto Rico and the U.S. Virgin Islands, and has prepared management plans for spiny lobster and shallow-water reefish fisheries. These plans place restrictions on types of gear which may be used for harvest, and establish minimum permissible sizes for harvested individuals of particular species. Other restrictions (e.g., closure of seasons or fishing areas) are also possible, but have not been enacted. Coastal Zone Management Programs have been prepared for Puerto Rico and the U.S. Virgin Islands as required by the Coastal Zone Management Act (PL 92-583), but contain no provisions directly relating to fishery management (Caribbean Fishery Management Council, 1984).

Puerto Rico has legal jurisdiction over fisheries within nine nautical miles of shore. The Department of Natural Resources is responsible for fisheries regulation, while responsibility for management and development rests with a semi-autonomous agency (CODREMAR) associated with the Department. The U.S. Virgin Islands has fishery jurisdiction within three miles of shore. The Department of Commerce is responsible for fishery promotion, while all other fishery affairs are assigned to the Department of Conservation and Cultural Affairs. Fishery advisory committees are appointed by the Commissioners of both Departments.

While much of the legal and institutional capability is in place, management of nearshore resources is hampered by a basic lack of information on the resources to be managed. A formal statistical program for Puerto Rico fisheries was started in 1967 as part of the Commercial Fisheries Research and Development Program (PL 88-309), and a variety of activities were undertaken during the early 1970's through the College of the Virgin Islands to provide information needed for rational development of nearshore marine resources of the U.S. Virgin Islands. These efforts necessarily have been primarily concerned with characterizing the fishery sector in general, and understandably have not focussed upon specific resources within the sector. As a result, while essential preliminary information has been obtained, details for most species are not sufficient to permit the reliable estimates of sustainable yield and fishing effort essential to rational management and development.

#### C. Principal Factors Affecting Harvest and Management

Three factors have had a major effect upon harvest and management of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands:

- ✓ 1. Limited resource base -- The relatively small size of naturally productive marine areas means that the absolute magnitude of the potential harvest is correspondingly small. Even so, the harvest can be of significant importance to local

residents and local economies; fisheries in these islands are still million-dollar industries. But nearshore marine resources are particularly vulnerable to overexploitation and island fisheries are easily overcapitalized.

2. Access to sophisticated exploitation technologies -- ✓  
Because they are territories of the United States, Puerto Rico and the U.S. Virgin Islands have relatively easy access to state-of-the-art marine harvest technology. There are few obstacles to entry of fishermen from the U.S. mainland who are typically well-versed in the application of such technology, while capital for fishing operations is more readily available than in other Caribbean islands. These circumstances favor development of fishing fleets whose harvest capacity greatly exceeds the productive capacity of nearshore marine ecosystems. 35

3. Unplanned and unrestricted growth in the fishery harvest sector -- Olsen and Wood (1983) characterize development in the U.S. Virgin Islands as "rampant and unplanned", and cite as one consequence a tripling of the population since 1960. The growth of the fishing fleets in Puerto Rico and the U.S. Virgin Islands coupled with a relatively small resource base has had a predictably negative impact upon target stocks. Planned development of these fleets is difficult, however, without reliable indications of natural capacity to support harvest. 36 ✓

D. Forecast of Effects of Continued Exploitation Trends

The growth of fishing fleets in Puerto Rico and the U.S. Virgin Islands has been closely linked with development of local tourist industries. Considering the prominent role of tourism in current development plans for Puerto Rico and the U.S. Virgin Islands, it seems likely that without a more directed approach to innovation and growth, pressure on nearshore marine resources is likely to increase. 37

Csirke (1984) describes six phases which typically characterize the history of an exploited fishery: 38

1. predevelopment
2. growth
3. full exploitation
4. over-exploitation
5. collapse
6. (sometimes) recovery

While information is not adequate to permit definitive evaluation, spiny lobster and shallow water reefish fisheries, and possibly conch and deepwater demersal fisheries in Puerto Rico and the U.S. Virgin Islands appear to be in phase 3 or 4. The implications to development are clear: Substantial improvements are unlikely if the "traditional" course of fisheries development in Puerto Rico and the U.S. Virgin Islands is continued. 39

Besides overexploitation, nearshore marine resources are jeopardized by the destruction of critical habitats discussed above. In 1979, the leading specific problem identified by both commercial and recreational fishermen was water contamination (Clapp and Mayne, 1979). Dredging and shoreline modification associated with tourist developments are a major threat to nearshore resources, both in Puerto Rico and the U.S. Virgin Islands. Juhl and Dammann (1976) noted that coral reefs in Puerto Rico are being "seriously threatened by human activity," including dredging, land erosion, oil, industrial and thermal pollution, and direct harvest (for curios). While a pragmatic justification for these activities might be based on the relative dollar returns from tourism vs. fishing, it should be remembered that many of the features which attract tourists are inextricably linked with the quality of nearshore ecosystems (coral reefs, sport fishing, fresh seafood, clean beaches, etc.).

40 || \*

Obviously, these trends are not unique to Puerto Rico or the U.S. Virgin Islands. But because of their relatively small size, these islands have less capacity than most territories to absorb the consequences of mismanagement. There are few or no adjacent areas to which fishermen or tourists can move when nearshore environments are seriously damaged. The strong dependence upon one productive sector (tourism) make local economies highly vulnerable to any circumstance which adversely affects this

41 |||

sector. The same consideration of limited "buffer" capacity applies to nearshore marine ecosystems. Coral reefs, in particular, grow extremely slowly, and are dependent upon complex interactions between species. Alteration of these systems can produce changes which are essentially irreversible.

#### E. Impact of Potential Exploitation Technologies

42  
Given the susceptibility of nearshore marine resources to overexploitation, technologies which would materially increase the harvest capacity or efficiency of local fishing fleets should be expected to have a negative long-range impact. If currently harvested resources are being fished at or beyond maximum sustainable yield (as seems to be the case), effort within the fishing fleet must either be reduced or diverted to other stocks. The latter course is clearly the more desirable, and there probably are stocks which are presently underexploited, including squid, deepwater crabs (Olsen et al., 1978), and shark. But there is no reason to suppose that these stocks are less liable to overexploitation than others, and development of alternative fisheries should be based on reliable estimates of sustainable yield. While some innovations may be necessary to achieve optimum harvest of stocks which are currently underutilized, the limited extent of all nearshore marine resources requires that the impact of technological changes be carefully evaluated before widespread implementation throughout the fishing fleet.

In recent years, there has been increasing interest in technological innovations which may increase landings of desirable species by providing artificial shelters. In some cases, the artificial structures serve to aggregate target species, and natural production levels are not altered. In others, it seems possible that natural production has actually been enhanced which should allow harvests greater than would be possible without artificial enhancement. Prototype artificial reef projects in Montserrat, British Virgin Islands, and the U.S. Virgin Islands suggest that increased production of shallow-water fishes is possible using scrap automobiles and tires. Another approach involves the use of structures designed specifically to increase production of selected species. A recent study in Florida indicates that fish biomass on Japanese "designed reefs" was two to six times greater than on scrap metal "reefs" (Schmeid, 1985).

43

||

A variety of mid-water fish aggregating devices (FADs) is being used experimentally in the Lesser Antilles. Studies by the U.S. Virgin Islands Division of Fish and Wildlife have shown that catch rates are significantly increased by deployment of FADs. Units installed close to the edge of the coastal shelf are reported to attract many migratory pelagic species, particularly dolphin; an estimated 30 - 40 large dolphin may be caught each day around a single FAD (J. LaPlace and R. Gomez, personal

|| 44

take to

fish

communication, July, 1985). The impact of this technology on fish stocks and sustainability of these catch rates has not been evaluated.

In summary, there is a variety of potential exploitation technologies which could improve fish landings as well as management of currently overexploited species (by diverting fishing effort to other stocks). But because of the limited nature of nearshore marine resources, the long-term impact of most innovations is likely to be negative unless their implementation is consistent with the productive capacity of the stocks<sup>x</sup> be harvested.<sub>^</sub>

45

#### F. Requirements and Impacts of Resource Management Technologies

Considering current patterns of use and development described above, three major activities appear necessary to achieve sustained development of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands:

46

✓ 1. Management plans must be developed for major nearshore ecosystems. Because fisheries of Puerto Rico and the U.S. Virgin Islands are characterized by a diversity of species rather than commercially important quantities of single species, efforts to manage these resources also should be focussed on groups of species or systems. A recent report by the World Resources Institute suggests that preservation and enhancement of the living marine resource harvest requires development and

47

application of an ecosystem conservation principle whereby all associated species, the relevant habitat, and spawning and nursery areas are jointly managed. // *high*  
*low*

Fishery management plans being developed by the Caribbean Fishery Management Council (CFMC) provide an excellent starting point for sustained development of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands. Their primary shortcomings are that they are intended to focus on single species or groups of species rather than entire systems, and must address currently exploited species before consideration can be given to underexploited resources. Under a broader mandate, the CFMC could oversee the acquisition and synthesis of information to provide for 48  
  
//

- a. preparation of a strategy for controlled development of nearshore marine ecosystems
- b. management and development plans for specific underutilized resources
- c. continued monitoring of the condition of ecosystems and utilized stocks

The CFMC is not expected to undertake such tasks unilaterally; rather, involvement of academic, government, and private voluntary agencies is envisioned with overall coordination by the Council. 49

50

57

✓  
I guess I see

The concept of limiting the number of participants in a fishery ("limited entry"; Rettig and Ginter, 1980) is a formallized process in some industrialized nations as well as in various small-scale traditional fisheries (e.g., Klee, 1978; Spoehr, 1980; Johannes, 1978). In the latter cases, limited entry has evolved as an integral part of community function, rather than as part of a formal system of policy and management. Bermuda has recently instituted a system to limited participation in local fisheries to those fishermen who operate on a full-time basis.

Limited entry systems are only partially effective in regulating effort, because fishermen typically increase their effort (and sometimes harvest efficiency) when such systems are imposed. Still, it is clear that unregulated expansion of local fishing fleets is contrary to optimum sustained use of nearshore fisheries in Puerto Rico and the U.S. Virgin Islands. Action which would prohibit a portion of current fishermen from further participation in local fisheries is probably not politically realistic. However, less opposition would be anticipated to freezing participation at current levels. In the case of resources which are not heavily utilized at present, more rigorous constraints could (and should) be applied to limit the number of fishing units to a level expected to be less than that corresponding to maximum sustainable yield. Such restrictions

could obviously be modified from time to time as better information became available on resource abundance; in fact, trial commercial fishing may be the best means for obtaining sustainable yield estimates in small island fisheries (Munro, 1983).

3. Initiatives by local organizations to improve management of nearshore marine resources must be encouraged. Of particular relevance are the activities of the Virgin Islands Resource Management Cooperative (VIRMAC; cf. Rogers and Zullo, 1985). This group consists of 14 federal and territorial government agencies, as well as private research and educational institutions from the U.S. Virgin Islands, British Virgin Islands, and Puerto Rico. VIRMAC is involved with developing management strategies for the Virgin Islands Biosphere Reserve. A variety of potential benefits to nearshore fisheries are associated with this activity including improved information on major stocks and ecosystem processes, establishment of breeding reserves for heavily exploited or threatened species, and provision of information needed for rational development of underutilized species. Because of the commonality of marine resources, these benefits may also be significant to other Lesser Antillean countries, and prospects for a multi-site regional Biosphere Reserve are being investigated.

54

The University of Puerto Rico is involved in a variety of activities relevant to development and management of nearshore marine fisheries. The Sea Grant Program at UPR, Mayaguez has recently extended its Marine Advisory Service to the U.S. Virgin Islands in cooperation with the College of the Virgin Islands (St. Thomas) and West Indies Laboratory of Fairleigh Dickinson University (St. Croix). This service provides an important means of linking research and policy agencies with resource users (fishermen, tour operators, etc.). Recent proposals for assessment of deepwater resources and evaluation of passive gears around Puerto Rico and the U.S. Virgin Islands are indicative of UPR's potential involvement with nearshore marine resource management issues.

It is clear that continuation of current trends in development and exploitation of nearshore marine resources in Puerto Rico and the U.S. Virgin Islands will result in

- ✓ - negative impacts upon the natural resources due to overexploitation and habitat destruction
- ✓ - negative economic impacts as fishery landings decline in response to excessive harvest pressure
- ✓ - negative social impacts due to reduced income to fishermen and other businesses dependent upon diminished resources

Because the proposed activities will reduce or avoid these impacts, the net result of proposed action is expected to be

positive. Because fishery management plans are targeted toward optimum economic yield, the impact of such plans by definition cannot be negative. The CFMC, for example, has calculated that implementation of proposed management measures for yellowtail snapper and Nassau grouper would reduce economic benefits by about \$67,000 after one year, but would provide positive benefits thereafter which would total more than \$4.5 million after ten years.

Common objections to limited entry measures are reduction in available jobs and possibly reduced supply of seafood due to decreased numbers of fishermen. These objections do not apply to the activities proposed here because

57

- the number of fishermen would be stabilized, not decreased
- the supply of seafood should be expected to increase due to improved management of overexploited resources and identification of underexploited stocks

Local initiatives for management at the ecosystem level will provide a counterpressure for trends toward degradation of critical habitats. Maintenance of these habitats will have a positive impact not only on fisheries, but also on recreational and tourism sectors.

58

lots of  
reasons to  
preserve  
habitats //

### III. Aquaculture

#### A. Potential for Aquaculture Development

Puerto Rico has excellent potential for development of viable aquaculture projects involving a variety of species

59

(Glude, 1980; Pagan-Font, 1982) as indicated by the following conditions:

1. Environmental Factors: Puerto Rico receives easterly trade winds throughout the year, and has a generally mild tropical climate. The island is mountainous, and level lands occur primarily in the coastal plain. Major cities, industrial development, and sugar cane fields occupy much of these plains. Areas with elevations less than 700 ft generally have high enough temperatures to support year-around production of certain warm water species. More cold-tolerant species, such as channel catfish (Ictalurus punctatus), could be reared at somewhat higher altitudes. However, the lower elevations of the coastal plains are generally recommended as primary locations for aquaculture farms. The south and southwest coasts of the island are the most protected from storm waves by offshore bars, reefs, and islands. Fresh, brackish and salt waters of reasonable quality and sufficient quantity are available in numerous areas. Soils suitable for pond construction are present in a number of places, including much of the land now used for sugar cane (Glude, 1980). 60

2. Economic Factors: Coastal lands near urban areas are often unavailable or prohibitively expensive, but large areas of agricultural and rural lands could be used for aquaculture. Some of these lands may be too saline for productive agriculture, but may be suitable for production of marine or salt-tolerant species such as Tilapia. Because of the depressed prices for sugar, property currently used for sugar cane production may become 61

available for aquaculture uses if the profit potentials appear favorable.

In general, Puerto Rico has a well-developed infrastructure. There is excellent air transportation among its major cities and between neighboring islands and the U.S. mainland. There are good surface transportation links between Puerto Rico and the mainland and, because Puerto Rico imports more from the mainland than it exports, favorable haul-back rates are probable for island products. There is a good local highway system, and more than 80% of homes have electricity. Processing, packaging, transportation, construction, and financial industries are well-developed, and there is easy access to equipment and other materials from the U.S. The government and economy are very stable and U.S.-based. Materials and services, including research, extension, and both skilled and unskilled labor are available. Unemployment is relatively high and per capita income low by U.S. standards. The University of Puerto Rico provides students with good training and research experience in aquaculture, but experienced hatchery and farm managers may have to be brought in from other areas. Puerto Rico has a major agricultural tradition and a relatively large farm-oriented population.

Substantial domestic markets are available for fishery products, and a burgeoning tourist industry could absorb significant amounts of high value products such as shrimp, prawns, lobsters, oysters, and marine fish. Surplus production would likely find ready acceptance in mainland markets.

62

63

Overall, Puerto Rico has good potential and a number of suitable sites for

64

- a. hatcheries for freshwater and especially marine species
- b. fresh, brackish, and saltwater ponds with sufficient land to support commercial operations
- c. cage, pen, and raft culture in coastal waters

In contrast, the U.S. Virgin Islands appear to have much lower potential for aquaculture development. In terms of climate, the U.S. Virgin Islands are very similar to Puerto Rico. However, the former are much smaller (344 sq km compared to 8897 sq km), with too little suitable land for development of large land-based aquatic farms. There appears to be limited potential for development of saltwater hatcheries and cage/pen culture of fish in coastal waters, but this potential has not yet been adequately researched. Tourism is the main industry, and any aquaculture product would likely find a ready domestic market.

|||

B. Applicability of Various Types of Aquaculture to the U.S. Caribbean

1. Extensive aquaculture is characterized by low stocking density, a relatively low level of environmental control and management, little or no supplemental feeding, and low yields per unit area. Typically, large expanses of low-cost coastal land are required, and they are usually supplied with stockable juveniles captured from the wild (e.g., shrimp farms in Ecuador; milkfish farms in southeast Asia). Small-scale (i.e., "backyard pond")

65

extensive aquaculture is practiced in some areas (e.g., Tilapia farming in Africa), more for subsistence than for profit production. Such small farms are likely to require support from a seed production/collection and distribution service.

For most species likely to be of major interest in the Caribbean, Puerto Rico and the U.S. Virgin Islands lack both the land and seed resources to support the development of extensive commercial aquafarms. In Puerto Rico, there is potential for development of small, backyard farms for Tilapia, freshwater prawns, and perhaps other species to provide supplemental income for rural people. However, such development is likely to occur only if the government establishes some sort of seed supply service. One attractive means of doing this, and an alternative to construction of a government hatchery, is for the government to contract with private business for production and distribution of the necessary seed. In this manner, government could encourage the development of both seed supply and grow-out operations in the private sector. Larvae of the mangrove oyster, Crassostrea rhizophorae, are available in coastal waters and might support some form of limited cultivation in protected bays. This oyster, however, is not considered to be a prime product and would require great care with regard to public health considerations.

66

2. Semi-extensive pond culture is characterized by generally smaller, more engineered and manageable ponds than many of those used for extensive aquaculture, significantly greater control over the pond environment through manipulation of water flow,

67

aeration, fertilization, etc., higher stocking density with heavy or complete reliance on a hatchery for supply of seed, and moderate to heavy reliance on supplemental feeds. Costs and yields per unit area are generally much higher than in extensive ponds. Examples of semi-intensive pond culture include catfish farming in the U.S., prawn farming in Hawaii and Jamaica, Tilapia farming in Jamaica, and now many of the more successful shrimp farms in South America and elsewhere.

For semi-intensive aquaculture to be successful, suitable sites for both hatchery and grow-out operations must be available. Both Puerto Rico and the U.S. Virgin Islands have excellent sites for hatcheries for a variety of saltwater species (Glude, 1980), and Puerto Rico has adequate land with suitable soils for development of commercial farms for fresh-, brackish-, and salt-water species (Glude, 1980). Some aquafarm development of this type is already underway in Puerto Rico (e.g., Sabana Grande Prawn Farms, Ltd.), and semi-intensive pond culture of various species is likely to be a major area of commercial aquaculture development for the island in the future. 68

3. Intensive culture characteristically involves a high degree of control over the environment such as can be attained in tanks and raceways, high stocking densities, complete reliance on artificial feeds, and very high productivity per unit area. Intensive culture systems require a high-technology approach and generally involve heavy water use, such as in flow-through raceways, or filtration and water reuse. To date, most intensive 69

aquaculture systems remain in the experimental or pilot phases of development (e.g., Marine Culture Enterprises' highly intensive shrimp farm in Hawaii), with few having attained commercial viability (e.g. raceway culture of trout and catfish in Idaho and California). Intensive aquaculture systems are not recommended for the U.S. Caribbean because of the lack of a proven, transferable technology for most species, the very high degrees of experience and management necessary to make such systems work, a lack of suitable conditions/sites for proven systems, and the very high level of risk involved. There have already been some notable and costly failures of intensive culture systems for freshwater prawns (Florida and California), lobsters (the Caribbean and elsewhere), shrimp (Chicago), and oysters (Hawaii).

4. Cage and pen culture involve the placement of cages, net-pens, rafts or other culture enclosures in lakes, rivers, estuaries, and coastal bays. This type of production is used primarily for fish, but raft culture of some molluscs (e.g., scallops) is practiced in some areas. Pen culture of fish generally requires intensive management; very careful site selection to insure protection from damaging waves currents, and winds, but with sufficient depth and flow to provide adequate flushing; high stocking rates; complete reliance on artificial feeds; and control of diseases, parasites, and fouling. Several species of fish are being successfully cultured commercially in net-pens or cages in various areas of the world. At present, most investigations of cage culture potential for Caribbean finfish

70

appear to have been done in Martinique where preliminary results indicate that yellowtail snapper (Ocyurus chrysurus), permit (Trachinotus falcatus), palometta (Trachinotus goodei), and European sea bass (Decentrarchus sp.) have commercial potential. Other species under investigation elsewhere and deserving consideration for the U.S. Caribbean include redfish (Sciaenops ocellata), epinephild groupers, striped bass (Morone saxatilis) and its hybrids, Tilapia, dolphin (Coryphaena sp.), and amberjack (Seriola dumerili). Numerous sites with reasonable characteristics for cage and pen culture of fishes appear to be available in Puerto Rico and to a lesser extent in the U.S. Virgin Islands. Because of heavy reliance of these islands on imported products to meet their demand for fish, evaluation of this means of increasing domestic production should be given a high priority.

5. Sea ranching generally involves the production of juveniles of an aquatic species in a hatchery with subsequent release to the wild to enhance natural populations. Although this procedure has been attempted with a variety of species, including shrimp, it is perhaps best known and most widely practiced for salmon. To be successful, such stocking programs must be accompanied by strong measures to control fishery pressure, possibly with habitat protection and/or enhancement. In the Caribbean most interest in sea ranching has focused on the queen conch because of declining stocks due to heavy fishing pressure throughout the region. There appears to be

71

potential for developing a hatchery technology adequate to support a release program (Siddall, 1983). Preliminary data indicate a possible positive impact of stocking, but only if the stocked cohort has adequate habitat and is protected from fishing pressure until after it reaches reproductive age (Appeldoorn and Ballantine, 1983; Ballantine and Appeldoorn, 1983; Iversen, 1983). Although not directly aquaculture, habitat enhancement (discussed above) often yields good results and deserves research attention.

#### C. History of Aquaculture in Puerto Rico and the U.S. Virgin Islands

Neither Puerto Rico nor the U.S. Virgin Islands has an extensive history of aquaculture development, though both appear to have good potential for aquatic farming. Aquaculture development in Puerto Rico began around 1970 (Pagan Font, 1982) or 1971 (Glude, 1980) when research activities were initiated with tilapias, catfish (Ictalurus punctatus) and freshwater prawns (Macrobrachium rosenbergii). Commercial culture of freshwater prawns began in Puerto Rico in 1974 with the establishment of Caribe King Shrimp, Inc., later joined by Aqua Park West, Inc. Both farms failed following extensive flood damage sustained during hurricanes of 1975 and 1979 (Glude, 1980). A third small prawn farm, Shrimp Unlimited, Inc., was established in 1978 near Sabana Grande with eight acres of ponds. Expansion to 20 acres was begun in 1980, but a series of

management problems led the company to discontinue operations in 1982. This farm was subsequently reactivated by a new company Sabana Grande Prawn Farms, Ltd., currently in operation with an additional 100 acres of ponds under construction and a hatchery planned. Other investor groups are considering development of prawn farms, and aquaculture research and extension activities at the University of Puerto Rico are expanding.

In the U.S. Virgin Islands, aquaculture activities have been limited almost entirely to research and development efforts, most of which has been focused on the artificial upwelling project in St. Croix. This project evaluated the potential of using nutrient-rich deep ocean waters pumped to shore to grow algae which in turn were fed to various species of shellfish (Roels and Gerard, 1970). The research effort extended for more than ten years and while the concept proved technically feasible and much useful scientific data were collected, the economics of the system were not promising. The same facilities were briefly used as a shrimp hatchery. There does not appear to be any other significant aquaculture development in the U.S. Virgin Islands.

73

#### D. Social and Ecological Impacts of Previous Aquaculture Development

Because of the limited extent of aquaculture development in the U.S. Caribbean, social and ecological impacts have also been limited. Perhaps the most significant social impact is the encouragement of a certain degree of cynicism, particularly in

74

local financial circles, as to whether aquaculture projects can ever develop from research or pilot phases to viable profit-making enterprises. In balance, the failure rate for aquaculture companies has probably not been unusually high when compared to that of other small businesses based on new technologies or in highly competitive fields (e.g., restaurants). Because of the small scale of aqua-farm development, there has been little positive or negative impact on the labor force or on the seafood import situation. However, successful, large-scale development of aquaculture could yield important benefits in both these areas. Finally, the previous failures and lack of successful aquaculture development compared to some other areas with similar climate may have helped to promote the current expansion of aquaculture research and extension efforts in the region.

The primary ecological impacts of past aquaculture activities have been the introduction of exotic species, especially the tilapias and the Malaysian freshwater prawn into the wild in Puerto Rico.

Major implications of the above for future aquaculture development in the U.S. Caribbean are as follows:

1. Proposed commercial aquaculture projects should be evaluated following criteria listed in Appendix 1, and only those with the highest potential for commercial success or social benefits within a reasonable time period should receive

government-backed loans or investment incentives. Public support for research and extension activities should be increased.

2. Where possible, local businesses, universities, etc. should be involved in projects from their inception. Individuals in such institutions know the local environment and business conditions and can help prevent failures caused by attempts to directly transfer culture technology which is not suited to local conditions.

78

3. Native species should be evaluated for commercial culture potential prior to wholesale introduction of non-indigenous species. When competition makes it necessary to introduce exotic species, safeguards prescribed by the International Council for the Exploration of the Sea should be instituted.

79

#### E. Criteria for Successful Aquaculture Projects

Aquaculture projects that are likely to be successful should first be based on species that can be grown under ambient environmental conditions. Projects should be carefully planned, with detailed answers to at least the key questions listed in Appendix 1.

80

#### F. Requirements and Expected Impacts of Appropriate Aquaculture Technologies

Aquaculture technologies considered by the authors of this report to be appropriate for possible application in Puerto Rico include:

81

1. pilot-scale evaluation of the extensive type of marine algae (Gracilaria sp.) culture which has shown promising results in St. Lucia
2. hatcheries for prawns, shrimp, and various fish species
3. semi-intensive pond culture of prawns, shrimp, Tilapia, catfish, and possibly one or more species of marine fishes
4. cage or pen culture of one to several species of marine fish
5. habitat enhancement and protection, perhaps coupled with very site-specific stocking programs, to availability of target species in the wild

Major requirements and anticipated impacts of these types of aquaculture development are summarized in Appendix 2. Positive impacts of such development include increased employment opportunities, reduction of imports, development of export products, support to local aquaculture ventures by providing seed or brood stock, improved use of marginal agricultural land, and potential increases in standing stocks of certain commercial fishery species. The most probable negative impacts are possible removal of a few coastal areas from general public access, and introduction or inadvertent release of non-native species. Negative impacts may result from small or even unsuccessful ventures, while the magnitude of benefits will depend largely upon the eventual scale of successful aquaculture operations.

§2

The potential for aquaculture development in the U.S. Virgin Islands is believed to be much lower than in Puerto Rico, largely due to the very small size of the islands and their rugged terrain. There does appear to be limited potential for development of hatcheries to supply cage culture operations or farms in other locations. The best potential is probably for cage/pen culture of fish, and for habitat enhancement activities.

83

#### IV. Relationships Between Capture Fisheries and Aquaculture

Development of both capture fisheries and aquaculture in Puerto Rico and the U.S. Virgin Islands is constrained by the limited area suitable for these activities. There are, however, significant opportunities for improvements in both sectors which depend substantially upon development-oriented research. Optimum use of nearshore marine resources probably requires attention to both aquaculture and capture fisheries. Wild stocks are needed to supply seed or brood stock for many aquaculture operations, and in fact some aquaculture opportunities (sea ranching and habitat enhancement) are essentially manipulations to natural productive processes in the wild. Aquaculture, on the other hand, can provide adjunct or alternative opportunities to fishing enterprises which are presently marginal, and may have the potential to rehabilitate overexploited stocks.

84

In some cases, aquaculture production has resulted in unfavorable competition for some commercial fisheries (e.g., shrimp). Such impacts seem unlikely in Puerto Rico and the U.S.

85

Virgin Islands, because demand greatly exceeds potential harvest from natural production. A ready market exists for products of both capture fisheries and aquaculture, and appears sufficiently diverse to accommodate foreseeable production from both activities.

Infrastructure (processing, transportation, research, extension, etc.) requirements are largely similar for both aquaculture and capture fisheries, and is either already in place or readily accessible. 86

Aquaculture involves a high degree of commitment to particular species and possibly to particular product forms. Capture fisheries, being based on multispecies resources, are inherently more flexible and hence are somewhat less susceptible to adverse impacts caused by changing markets. Both are vulnerable to competition from imports. The element of risk inherent in both activities poses a common constraint to credit and insurance. The best approach to this problem is to reduce risk by improving the availability and application of appropriate technology through activities recommended below. 87

Aquaculture ventures, like capture fisheries, may face problems of resource access. The issue is fairly straightforward for land-based aquaculture, where land tenure systems are well-established. On the other hand, it is very difficult to maintain exclusive rights to production from sea ranching and habitat enhancement ventures because these activities use resources which are traditionally considered common property. 88

Similar conflicts often arise in regard to use of flowing freshwaters or estuaries.

Many of the potentials and constraints to development of capture fisheries and aquaculture in the U.S, Caribbean also 89 apply to most of the other Lesser Antilles. As a result, there are important opportunities for joint marine resource development ventures between the U.S. territories and the Eastern Caribbean countries. It is emphasized that these opportunities do not primarily involve transfer of U.S. mainland technology, but rather are for collaborative development of technologies appropriate to small-island circumstances. This does not involve an exclusively south-flowing stream of benefits; activity in the independent Eastern Caribbean countries can provide benefits to Puerto Rico and the U.S. Virgin Islands, as illustrated by the development of algae and fin fish culture techniques discussed above.

## V. Summary

### A. Problems and Opportunities

Sustainable development of aquaculture and fisheries in Puerto Rico and the U.S. Virgin Islands are constrained by 90

1. the limited extent of nearshore marine resources
2. current development trends likely to result in overexploitation

3. inadequate information on which to base management of currently exploited resources or to develop those which are underutilized
4. absence of experience with successful commercial culture of endemic nearshore marine species, and absence of proven technologies for such culture
5. high incidence of ciguatera which causes consumers to reject an unknown but probably significant portion of fish landings

These problems highlight important opportunities to

1. Maintain the current value of nearshore marine resources through effective management, and probably increase benefits through appropriate development of underutilized resources
2. Improve information to manage and develop of these resources
3. Adapt and develop techniques for commercial culture of endemic nearshore marine species
4. Improve the utilization of the current catch by developing a means for rapid detection of ciguatoxic fishes
5. Assist and benefit from efforts in other Caribbean countries to manage common nearshore marine species

B. Relevant Agencies, Policies, Programs and Regulations

For the most part, these opportunities can be addressed through existing local and U.S. federal agency policies and programs. The Caribbean Fishery Management Council is an appropriate vehicle to coordinate development of management plans for nearshore marine systems. The standards established by the

Fishery Conservation and Management Act for fishery management plans are consistent with optimum sustainable development of fisheries, and are appropriate to nearshore marine systems as well as individual species. Sustainable development of fisheries and aquaculture is also consistent with the Coastal Zone Management Program of Puerto Rico and the U.S. Virgin Islands. Regulatory authority currently vested in the Puerto Rico Department of Natural Resources and the U.S. Virgin Islands Department of Conservation and Cultural Affairs appears adequate to support the activities discussed below.

Particularly significant programs through which financial support may be provided for these activities include

92

- the National Sea Grant College Program (especially for developmental aquaculture research)
- Dingell-Johnson Act (PL 81-681), which derives funds from a 10% excise tax on fishing rods, creels, reels, artificial lures, baits and flies, and provides support to individual states for fisheries management, habitat protection, and improved public access to fishing waters
- Saltonstall-Kennedy Act (15 USC 713c-2-713c-3) provides that up to 30% of gross receipts collected from import duties on fishery products may be made available to assist research and development projects concerned with U.S. fisheries

Local institutions in Puerto Rico and the U.S. Virgin Islands have demonstrated capabilities for undertaking much of

93

the work needed to realize the opportunities described above. The College of the Virgin Islands through its Virgin Islands Ecological Research Station and the Department of Conservation and Cultural Affairs have undertaken a variety of studies of local fisheries potential (e.g., Dammann, 1969; 1970; Brownell and Rainey, 1971; Olsen et al., 1975; Sylvester et al., 1977). Activities of the University of Puerto Rico and the Virgin Islands Marine Resource Management Cooperative were described in section II.F. Collectively, these institutions have the ability to undertake investigations to provide information needed for preparation of development and management plans for nearshore marine systems.

Considering the limited extent of nearshore resources and indications of probable overfishing, credit and incentive programs for purchase of vessels and gear (e.g., the program for Fishery Credit conducted by the Agricultural Credit Corp.) probably are not conducive to sustainable development of fisheries. Such programs are consistent with the latter objective only when the fishing effort being capitalized is directed toward resources which are known to be underexploited. At present, there is no apparent control over how the vessels and gear are to be used, nor is it clear that the number of vessels supported has been related in any way to the capacity of nearshore systems to support harvest.

These concerns apply to the impact of the Caribbean Basin Initiative (CBI) on nearshore fisheries throughout the Lesser

Antilles. Stimulated by CBI, a number of projects related to fisheries and aquaculture have been proposed or implemented in the Lesser Antilles. Available information indicates that these projects typically involve direct transfer of technology from temperate locales to small tropical island circumstances. Projects which involve harvest from wild fishery stocks are based upon overly optimistic yield projections, and are not formulated with a view toward sustainability or resource protection. One project proposed for Grenada involved dredging for conch (G. Thompson, personal communication) -- an obviously destructive approach to harvesting a species which is considered to be "threatened as an economic resource" (Goodwin, 1983). Aquaculture projects have been presented as virtually assured of success, despite the checkered history of such projects globally, lack of site-specific pilot evaluations, and logistic difficulties characteristic of small islands.

Evidence from Puerto Rico and the U.S. Virgin Islands strongly suggests that harvest technology is not the problem. Rather, the need is to apply appropriate technology at a level suited to the productive capabilities of natural systems. Continuation of a development style directed solely toward capitalization and harvest efficiency without regard for sustainable yields can only result in resource depletion and adverse socioeconomic impacts. Because of the similarity and probable sharing of marine resources among the Lesser Antilles, it is important that an alternative development style be adopted

96

for CBI fisheries projects as well as similar projects in the U.S. territories. There is a similar need for aquaculture projects which are understood to be technology development and site-specific adaptation activities, rather than guaranteed vehicles for fast profits.

C. Objectives

1. Promote formulation and implementation of a rational plan for development, use, and protection of nearshore marine ecosystems in Puerto Rico and the U.S. Virgin Islands.
2. Augment current efforts to develop a field test for identification of ciguatoxic fishes.
3. Stimulate development and application of technology for commercial culture of endemic marine species.
4. Promote international cooperation in managing common fishery species.

97

D. Recommended Action

1. The Caribbean Fishery Management Council should:
  - a. identify information needed to prepare development and management plans for nearshore marine ecosystems of Puerto Rico and the U.S. Virgin Islands, with specific attention to evaluation of underutilized species
  - b. identify institutions in Puerto Rico and the U.S. Virgin Islands capable of investigations to provide this information

98

- c. identify required services which cannot be undertaken by local institutions or agencies
- d. investigate means for stabilizing and limiting harvest effort in current fisheries of Puerto Rico and the U.S. Virgin Islands and for controlling fishing pressure on underutilized resources as these are developed, and make appropriate recommendations to the Secretary of Commerce

2. Based on the recommendations of the CFMC, local government, academic, and non-profit institutions should prepare proposals to support relevant activities under applicable funding programs, and upon receipt of funds should undertake these activities in coordination with the CFMC. 99

3. The University of Puerto Rico and Medical University of South Carolina, in collaboration with other agencies and institutions in Puerto Rico and the U.S. Virgin Islands, should expand the current research program directed toward developing a field test for ciguatoxic fishes; consideration should be given to obtaining potentially toxic material through recreational fishing vessels. 102

4. Support should be provided through the Sea Grant College Program for development and evaluation of aquaculture techniques applicable to Puerto Rico and the U.S. Virgin Islands, particularly those which can be used to culture marine species endemic to these territories. 101

5. The U.S. Caribbean territories and other countries of the Lesser Antilles should be encouraged to exchange information on 102

sustainable development of nearshore marine systems and aquaculture. In particular,

- a. The U.S. National Park Service should accelerate activity directed toward creation of a regional multi-site Biosphere Reserve
- b. The University of Puerto Rico, College of the Virgin Islands, and South Carolina Sea Grant Consortium should pursue development of a marine advisory network for the Eastern Caribbean
- c. The Gulf and Caribbean Fisheries Institute should continue and expand its technical sessions concerning sustainable development of small-island fisheries and aquaculture

6. The U.S. Department of Commerce should provide the CFMC with additional staff support needed to carry out the above tasks

7. The U.S. Congress should
- a. provide necessary mandates to the Department of Commerce to allow the CFMC to undertake the above tasks
  - b. insure that sufficient funds are available to accomplish these tasks through such vehicles as Saltonstall-Kennedy and Dingell-Johnson funds, and/or appropriations for the U.S. Sea Grant College Program and Regional Fishery Management Councils

#### E. Assessment of Consequences

At the minimum, the recommended actions may be expected to stabilize the current harvest at a level which will maintain the value of the current harvest from nearshore marine fisheries. But

103

because of overexploitation in the current harvest, it is reasonable to expect that implementation of realistic management plans will increase the economic value of the nearshore harvest as illustrated by the case of Nassau grouper and yellowtail snapper described above. Moreover, the location and development of underutilized stocks may be expected to further increase economic benefits from the nearshore fishery. Because no measures are proposed which would directly interfere with current fishing activity, negative social impacts upon fishermen are expected to be minimal.

While there is no guarantee of success, progress toward a simple screening test for ciguatoxic fish has been sufficient to warrant continued and accelerated effort. The development of such a test will improve use of current and future harvests by eliminating rejection of entire species of fish, some individuals of which are not toxic. 104

Aquaculture offers a variety of virtually unexplored opportunities to increase production of seafood for local and export markets. Because lack of appropriate tested technology is a current obstacle to realization of this potential, a dedicated program to provide such technology may be expected to encourage successful investment in culture enterprises. Progress in such technology can also be expected to suggest means by which wild stocks may be improved or rehabilitated (e.g., through habitat enhancement or stocking hatchery-reared juveniles into the wild). 105

Involving local institutions in a management and development process directed toward whole ecosystems may be expected to broaden appreciation for the interrelated nature of these systems, and their importance to local economies.

106

Collaboration with other Lesser Antillean countries on these activities will provide access to developments in other areas of potential use to Puerto Rico and the U.S. Virgin Islands. In addition, such collaboration will provide for better access to regional markets and sources of supply, and will help to improve economic, social, and political ties between the United States and the strategically important countries of the Eastern Caribbean.

107

Bibliography

- Anonymous, 1978. Puerto Rico Coastal Zone Management Program and Final Environmental Impact Statement. Office of Coastal Zone Management, Dept. of Commerce, Washington.
- Appeldoorn, R. S., and Ballantine, D. L., 1983. Field release o cultured queen conch in Puerto Rico: Implications for stock restoration. Proc. Gulf Carib. Fish. Inst. 35:89-98
- Ballantine, D. L., and Appeldoorn, R. S., 1983. Queen conch culture and future prospects in Puerto Rico. Proc. Gulf Carib. Fish. Inst. 35:57-63
- Berg, C. J., 1983. Report of the evaluation team on conch . mariculture. Proc. Gulf Carib. Fish. Inst. 35:135
- Brownell, W. N. and Rainey, W. E., 1971. Research and development of deepwater commercial and sport fisheries around the Virgin Islands plateau. Caribb. Res. Inst., Virgin Islands Ecol. Res. Sta. Contrib. No. 3, 88 p.
- Caribbean Fishery Management Council, 1984. Draft Fishery Management Plan, Regulatory Impact Review, and Environmental Impact Statement for the Shallow-water Reeffish Fishery of Puerto Rico and the U. S. Virgin Islands. CFMC, Hato Rey, Puerto Rico.

-----, 1980. Draft Fishery Management Plan for Spiny Lobster Fishery in Puerto Rico and the U. S. Virgin Islands. CFMC, Hato Rey, Puerto Rico.

Cato, J. C. and Prochaska, F. J., 1980. Economic management concepts in small-scale spiny lobster fisheries. Proc. Gulf Carib. Fish. Inst. 33:301-321.

Clapp and Mayne, Inc., 1979. Fishermen in Puerto Rico Socio-Economic Profile. Report to U. S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Southeast Fisheries Center, Miami.

Csirke, J., 1984. Report of the working group on fisheries management, implications and interactions. -in- J. Csirke and G. D. Sharp, eds. Reports of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources. FAO Fish. Rept. No. 291, Rome.

Dammann, A. E., 1969. Study of the Fisheries Potential of the Virgin Islands. Virgin Islands Ecological Research Station Contribution No. 1, St. Thomas.

Glude, J. B., 1980. A plan for the development of aquaculture in Puerto Rico. MS, Dept. Recursos Naturales CODREMAR, Commonwealth of Puerto Rico.

Goodwin, M. H., Orbach, M., Sandifer, P., Towle, E., 1985.

Fishery sector assessment for the Eastern Caribbean:  
Antigua/Barbuda, Dominica, Grenada, Montserrat, St.  
Christopher/Nevis, St. Lucia, St. Vincent & Grenadines.  
Report to Regional Development Office/Caribbean, U. S.  
Agency for International Development. Island Resources  
Foundation, St. Thomas.

-----, 1983. Overview of conch fisheries and culture. Proc.  
Gulf Carib. Fish. Inst. 35:43-45.

Iversen, E. S., 1983. Feasibility of increasing Bahamian conch  
production by mariculture. Proc. Gulf Carib. Fish. Inst.  
35:83-88.

Johannes, R. A., 1978. Traditional marine conservation methods in  
Oceania and their demise. -in- Ann. Rev. Ecol. Syst.  
(9):349-364.

Juhl, R. and Dammann, A., 1976. Review of the Status of Fishery  
Resources and Fishery Management Problems of the Caribbean  
Council Area. Report to U. S. Dept. of Commerce, National  
Oceanic and Atmospheric Administration, Southeast Fisheries  
Center, Miami.

Kawaguchi, K., 1974. Handline and longline fishing explorations  
for snapper and related species in the Caribbean and  
adjacent waters. Mar. Fish. Rev. 36:8-31.

Klee, G., 1978. Traditional Management Systems. Westview Press.  
Boulder, CO.

Klima, E. F., 1976. A review of the fishery resources in the  
Western Central Atlantic. WECAF Studies No. 3. FAO. Rome.

Munro, J. L., 1983. A cost-effective data acquisition system for  
assessment and management of tropical multispecies,  
multi-gear fisheries. Fishbyte 1:7-12.

-----, 1977. Actual and potential fish production from the  
coralline shelves of the Caribbean Sea. FAO Fish. Rept.  
200:301-321.

-----, 1974. The biology, ecology, exploitation and  
management of Caribbean reef fishes. Part VI. Assessment of  
the potential productivity of Jamaican fisheries. Res.  
Repts. Zool. Dept. Univ. West Indies No. 3. UWI. Kingston,  
Jamaica.

Olsen, D. A., Dammann, A. E., and La Place, J. A., 1978. Portunus  
spinimanus Latreille, a Portunid crab with resource  
potential in the U. S. Virgin Islands. Mar. Fish. Rev.  
40(7)12-14.

-----, -----, and -----, 1976. Demonstration of  
advances in Virgin Islands small boat fishing techniques.  
MS, Bureau of Fish and Wildlife, Dept. of Conservation and  
Cultural Affairs, St. Thomas.

Olsen, D. A., and Wood, R. S., 1983. The marine resource base for marine recreational fisheries development in the Caribbean. Proc. Gulf Carib. Fish. Inst. 35:152-160.

Oxenford, H. and Hunte, W., 1984. Age and growth of the dolphin Coryphaena hippuris. Fish. Bull. (in press)

Pagan-Font, F. A., 1982. Aquaculture: Investment opportunities in Puerto Rico. Proc. Gulf Carib. Fish. Inst. 34:73-75.

Panayotou, T., 1982. Management concepts for small-scale fisheries: Economic and social aspects. FAO Fish. Tech. Paper No. 228. FAO. Rome.

Peacock, N., 1976. Lesser Antillean Fisheries, Their Management and Development. MS. Ministry of Overseas Development. London.

Perez-Farfante, I., 1969. Western Atlantic shrimp of the genus Penaeus. U. S. Fish Wildl. Serv. Fish. Bull. 67(3):461-591.

Phelps, R. P., 1981. Environmental considerations in aquaculture. Report to U. S. Agency for International Development, Contract No. AID/SAN-C-0053. Auburn University. Auburn, AL.

Pillay, T. V. R., 1977. Planning of Aquaculture Development. Fishing News Books. Surrey.

Rettig, R. B. and Ginter, J. J. C., eds., 1980. Limited Entry as a Fishery Management Tool. Univ. Washington Press. Seattle.

Roels, O. A. and Gerard, R. D., 1970. Artificial upwelling.

Food-Drugs from the Sea Proceedings 1969:103-112.

Rogers, C. S., 1985. Degradation of Caribbean and Western

Atlantic coral reefs and decline of associated fisheries.

Paper presented at Fifth International Coral Reef Congress,  
1985.

-----, Suchanek, T., and Pecora, F., 1982. Effects of

Hurricanes David and Frederic (1979) on shallow *Acropora*  
*palmata* reef communities: St. Croix, U. S. Virgin Islands.

Bull. Mar. Sci. 32:532-548.

----- and Zullo, V., 1982. Research and resource management  
program at Virgin Islands National Park/ Biosphere Reserve.

Park Science 5:3.

Sandifer, P. A. and Smith, T. I. J., 1985. Freshwater prawns.

-In- Huner, J. V. and Brown, E. E., (eds.), Crustacean and  
Mollusk Aquaculture in the United States. AVI Publ. Co.,  
Inc., Westport, CT.

Schmeid, R., 1985. Saltonstall-Kennedy projects underway or  
completed. NMFS Newsbreaker 85-35.

Siddall, S. E., 1983. Biological and economic outlook for

hatchery production of juvenile queen conch. Proc. Gulf  
Carib. Fish. Inst. 35:46-52.

- Smith, A., 1984. Gracillaria culture in St. Lucia. MS presented at 37th Gulf and Caribbean Fisheries Institute, Cancun, Mexico.
- Spoehr, A., 1980. Maritime Adaptation: Essays on Contemporary Fishing Communities. Univ. of Pittsburgh Press. Pittsburgh.
- Suarez-Cabro, J. A. and Rolon, M. A., 1974. La Pesca en Puerto Rico, 1973. Departamento de Agricultura, vol. VI, no. 1.
- Swingle, W. E., Dammann, A. E., and Yntema, J. A., 1970. Survey of the commercial fishery of the Virgin Islands of the United States. Proc. Gulf Carib. Fish. Inst. 22:110-121.
- Sylvester, J. R., and Dammann, A. E., 1974. Some observations on the deepwater fishery resources of the Virgin Islands. Carib. J. Sci. 14:163-165.
- Vidaeus, L., 1970b. An inventory of the St. Kitts fishing industry. FAO Report SF/CAR/REG 189 M 14. FAO. Rome.
- Wood, R. S. and Olsen, D. A., 1983. Application of biological knowledge to the management of the Virgin Islands conch fishery. Proc. Gulf Carib. Fish. Inst. 35:112-121.
- Woodley, J., et al., 1981. Hurricane Allen's impact on Jamaican coral reefs. Science 213:749-755.

Appendix 1

Criteria for Successful Aquaculture Projects

(adapted from Goodwin et al., 1985)

1. Market Conditions

- a. Can the product be sold?
- b. Where?
- c. At what price?
- d. How much is needed?
- e. In what product form?
- f. Are there seasonal variations in demand, supply, price?
- g. Who else is supplying this market?
- h. What frequency of supply is required?
- i. Are there alternate markets?
- j. What are long-term trends and projections for demand, supply, prices?

2. Culture Technology

- a. How well developed is the culture technology?
- b. Who has it?
- c. What types of facilities are necessary?
- d. Can the organism be reared on a reasonably reliable and predictable basis at commercial scale?
- e. What are the culture requirements of all life history stages?
- f. What characteristics should ideal culture sites for this species have?

- g. How close to ideal is the chosen project site(s)?
- h. How available are seed, brood stock, feed, or other key elements?
- i. Are suitable native species available or will exotics have to be introduced?
- j. What handling procedures will be used for exotic species?
- k. What are typical growth and survival characteristics of the organism in culture?
- l. What, if any, pilot or commercial projects have been conducted with the species and with what results?
- m. What commercial projects with this species have failed and why?
- n. What kinds of consultants and skilled personnel will be necessary and are they available?

### 3. Environmental Conditions

- a. What are the physical (hydrological, meteorological, edaphic) and biological (productivity, availability of seed and brood stock, occurrence of diseases, predators, pollution) features of the site and are these suitable for production of the chosen species?
- b. Are all the necessary land, labor, transportation, communications, energy supplies, materials, services, and financing potentially available?
- c. Do government policies, cultural factors and the local legal framework (incentives, import-export restrictions, permits) favor aquaculture development?

- d. Will aquaculture fit in with other uses of the surrounding environment?

#### 4. Economic Outlook

- a. How large should the project be and why?
- b. Will projected revenues from the proposed project exceed estimated costs in a reasonable period of time?
- c. All costs and revenues to be incurred by the project should be estimated and a pro forma financial statement showing estimated expenditures and returns over a period of several years (usually 10) prepared.
- d. Costs, time requirements, and evaluation criteria for any pilot project should be specified.
- e. The type of business structure (e.g., corporation, limited partnership, sole proprietorship, etc.) should be described and the principals names, if possible.

## Appendix 2

### Requirements, Problems, and Impacts of Appropriate Aquaculture Technologies

#### A. Extensive Culture of Algae

1. Requirements: shallow, protected coastal waters with firm substrates and relatively high nutrient levels
2. Impacts
  - a. Potential Benefits: increased employment opportunities for relatively unskilled workers and development of an export product
  - b. Potential Negative Impacts: removal of fairly large areas of a few coastal bays and beaches from general public access and use.

#### B. Hatcheries for Freshwater Prawns, Marine Shrimp, and Various Species of Marine Fish

1. Requirements: Site requirements for all species are fairly similar, namely ready access to adequate supplies of seawater (and in some cases freshwater) and suitable temperatures. The larvae of shrimp and most of the marine fish species of interest require high salinities (e.g., 30 ppt or higher) for best results, while prawns need much lower salinities (12 - 16 ppt). Only small areas of land (one to few acres) would be required for most species; however, substantially larger areas (tens of

acres) would be needed for fish species requiring ponds for fingerling production (e.g., redfish, striped bass, etc.).

## 2. Impacts

- a. Potential Benefits: freedom from reliance on off-island seed suppliers, possibility of developing export sales of seed to other islands, and training local personnel in hatchery techniques
- b. Potential Negative Impacts: inadvertent release of exotic species or disease organisms

## C. Tilapia and Catfish

Tilapia require warm waters (generally 21 - 23 C or greater) for good growth and spawning. They are usually reared in freshwater, but several species grow well in brackish and salt water. The Tilapias are quite tolerant of low dissolved oxygen levels, and moderately tolerant of high ammonia and turbidity levels. Earthen ponds are the preferred production system, and the fish will spawn directly in the ponds. The major problem is controlling reproduction to prevent over-population of ponds with resulting severe decrease in growth rates. Like Tilapia, catfish require warm fresh waters, but can be cultured at somewhat higher elevations and lower temperatures. Catfish are less tolerant of poor water quality than Tilapia. The major requirement for culture of Tilapia and catfish will be suitable acreages of ponds.

There is good potential for production of Tilapia and catfish in Puerto Rico. The technologies are proven, and can be applied in monoculture and polyculture systems and at large commercial scale or small-pond scale to supplement income. Land and other resources necessary are available. Production from 1,500 to 2,000 acres of ponds would likely exceed total annual fishery landings from wild stocks in Puerto Rico and thus reduce the island's major dependence upon imported fish. In the future, production (at least of catfish) above that needed to meet local demand could likely be marketed in the mainland. Substantial market development work will probably be necessary for Tilapia, especially if any of the production is to be targeted for mainland markets.

#### D. Freshwater Prawns

Requirements are similar to those for Tilapia and catfish. Warm temperatures are particularly important since the optimum temperature for growth appears to be about 28 C. According to Glude (1980),

large areas of land, especially in the Lajas Valley, are suitable for prawn farming, and there is a good local market at high prices.

The technology for prawn culture is fairly well-developed, but not quite as well-proven as that for catfish and Tilapia. Currently, there are no hatcheries in Puerto Rico, although one

is reportedly under development. A local supply of seed will be essential for large-scale development.

Glude (1980) projected that by 1990 freshwater prawn farming in Puerto Rico might expand to more than 2,000 acres producing four million lb each year with a farm value of some \$20 million. This estimate is probably overly optimistic, but there is good potential for expansion to at least several hundred acres by the end of the decade. An important possibility is the use of marginal agricultural land underlain by brackish waters, such as occurs in the Lajas region, for prawn culture. Prawns do very well in low salinity environments (Sandifer and Smith, 1985). A major problem yet to be resolved is the development or identification of export markets of sufficient magnitude to absorb large quantities of product at prices that will yield profits. However, the domestic market, although not quantified, is believed to be sizeable, especially the tourist-oriented segment.

#### E. Marine Shrimp

1. Requirements: The major requirement is for salt water ponds in areas protected from storm damage and flooding. Sufficient acreage is needed to allow true commercial development (hundreds to eventually thousands of acres). The technology for pond culture is well-developed and hatchery systems are fairly reliable. The greatest technology weakness is in the area of maturation and reproduction of animals in captivity. Available

technology has been sufficient for an appreciable level of commercial development (one large farm in the U.S. relies almost entirely on captive reproduction), but there is a great deal of room for improvement. This is important since a local seed supply will eventually be needed to support farm development, and such a hatchery will have to be based on captive maturation since large stocks of shrimp do not appear to occur in Puerto Rican waters. With care, captive reproduction technology can be transferred to Puerto Rico and successfully adapted to local conditions.

## 2. Impacts

a. Potential Benefits: decreased reliance on imported products in both commonwealth and mainland markets via production of a high value product that can be sold locally or shipped to the U.S.; annual income of \$6 - 10 million from development of 1,000 acres of ponds each producing an average of 2,000 lb of shrimp tails per year

b. Potential Negative Impacts: introduction and inadvertent release of non-native species [in this regard it is significant that the naturally occurring Penaeus schmitti (Perez Farfante, 1969) has recently been found to be a good species for aquaculture (Weidner, 1985), with demonstrated captive reproduction and good growth characteristics (Sandifer et al., personal observations)]

#### F. Cage Culture of Marine Fish

1. Requirements: Coastal bays and estuaries with adequate flow to maintain water quality but protected from storm damage are needed for cage and pen production. Property protection will have to be developed through government policies. Sources of juveniles, either from hatcheries or from the wild, are also required. Market studies will have to be undertaken with non-traditional species, but demand is likely to be high.

##### 2. Impacts

a. Potential Benefits: substitution of domestic production for imports

b. Potential Negative Impacts: inadvertent release of introduced species; reduced public access to certain coastal waters; possible overharvesting of juvenile fish from the wild for seed

#### G. Habitat Enhancement

1. Requirements: Relatively shallow-water coastal areas that lack reefs and other vertical relief

##### 2. Impacts

a. Potential Benefits: increased standing stock of fish and perhaps other species such as spiny lobsters

b. Potential Negative Impacts: poorly anchored or located habitat units may wash ashore during storms